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NSG-2301

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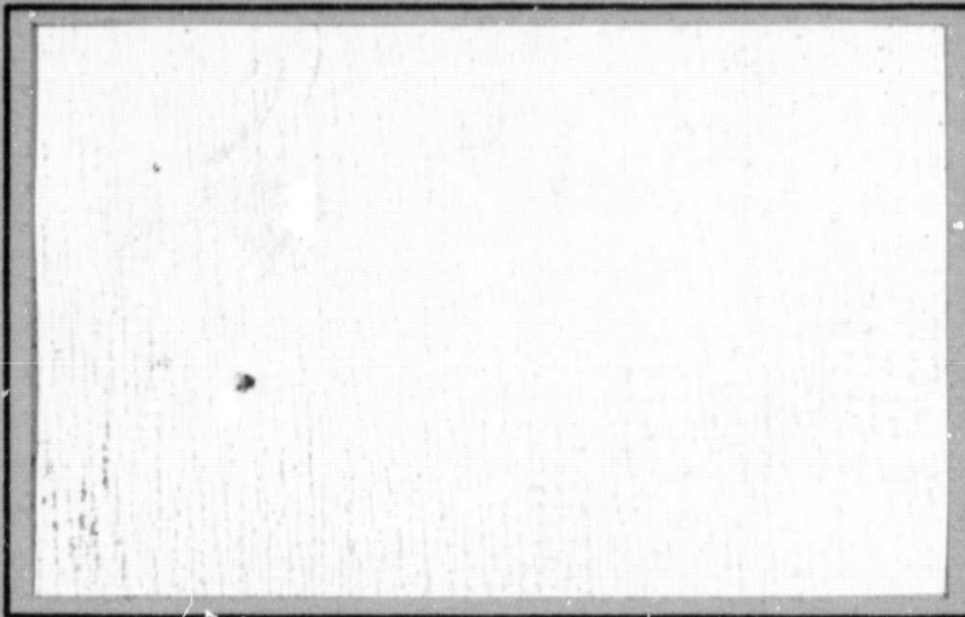
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A Three-Dimensional Turbulent Separated
Flow and Related Measurements

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A Three-Dimensional Turbulent Separated Flow and Related Measurements

Introduction

This final report summarizes the activities, the reports (both informal and formal), and the publications relating to NASA Grant NSG 2301 over the period April 1978 through September 1984.

Activities

The Grant activities covered consecutively two major areas of research.

Initially, the project continued some earlier work (initiated under NSF support) in reviewing and in determining the applicability of and the limits on the applicability of 11 near wall similarity laws from the literature specifically offered as characterizing three-dimensional turbulent boundary layer flows. This work required the use of a unique, direct force sensing local wall shear stress meter used in both pressure-driven and shear-driven three-dimensional turbulent boundary layers, together with extensive mean velocity field and wall pressure field data. This work resulted in a relatively large number of graphical comparisons of the predictive ability of 10 of these 11 similarity models relative to measured data over a wide range of flow conditions.

Subsequently, the project focused on documenting a complex, separated three-dimensional turbulent flow as a standard test case for evaluating the predictive ability of numerical codes solving such flows.

The particular flow selected was the horseshoe or junction vortex

flow generated by a streamlined, teardrop shaped body placed normal to a flat plate. While the thickness to chord ratio of this body was relatively large to develop large secondary flows in the upstream boundary layer, several features of this kind of flow characterize the flow at, for example, the junctions of a wing and body, of a control surface and body, of a compressor inlet guide vane and passage wall or hub, and of a submarine sail and hull.

The documentation of the flow field was done in two phases. Phase one documented the flow upstream and around, but away from the separation region and outside the junction vortex, where the flow is properly described as a three-dimensional turbulent boundary layer. The computations of such a boundary layer flow requires an initial condition plane to start a calculation and edge conditions to maintain the calculations. Additionally, measurements within the flow field are useful for comparison with the numerically predicted flow. In this work, the mean flow and turbulence measurements were made with hot film/wire anemometry.

Initial condition plane measurements, at multiple transverse positions, include:

- 1) mean velocity field,
- 2) turbulent kinetic energy, and
- 3) three turbulent normal stresses.

Measured edge condition data includes:

- 1) mean velocity, and
- 2) wall static pressure.

Flow field measurements include:

- 1) mean velocity (three components),
- 2) turbulent kinetic energy,
- 3) three turbulent normal stresses, and

- 4) selected indirect (Preston tube) wall shear measurements which indicate the earlier direct force wall shear measurements can be used with a modest change in uncertainty.

The actual turbulence measurements also included the three turbulent shear stresses. However, differences in agreement between the measured shear stress in a zero pressure gradient two-dimensional turbulent boundary layer and classic data in the literature were sufficiently large so as to question the validity of the shear stress measurements. Similar comparisons of the normal stresses gave good agreement, hence these data are considered valid.

Phase two of the project documented the flow in and around the separation sheet and the junction vortex itself. This work included:

- 1) extensive flow visualization of the tunnel floor-body junction both on the body and on the floor and extending well into the surrounding flow on the floor,
- 2) surface pressure measurements both on the floor and on the body, and
- 3) very extensive mean flow measurements of local velocity, static pressure, and total pressure on three planes in and around the junction vortex made with a carefully calibrated five hole probe.

All flow field measurements were made with an automated, microcomputer controlled data acquisition system. Large volumes of data, together with very extensive calibration of probes and transducers, resulted in data of exceptionally high quality. Uncertainties in all the very extensive data reported are precisely stated and are estimated by rigorous and formal statistical procedures at statistically meaningful levels of significance.

Publications

The results of the work under phase one have been extensively

published in the open (journal/symposia) literature. Results of the more recent work under phase two are in various stages of preparation for release in the open literature.

The following is a list of formal and informal reports relating to the total project.

Pierce, F. J., and J. E. McAllister, "Preliminary Results of Near-Wall Similarity Studies in a Pressure-Driven, Three-Dimensional Turbulent Boundary Layer," First Annual Report, NASA Grant NSG-2301, Mechanical Engineering, Virginia Polytechnic Institute and State University, April 1979.

Pierce, F. J., and J. E. McAllister, "Near-Wall Similarity in a Pressure-Driven Three-Dimensional Turbulent Boundary Layer," Rpt. VPI-E-80.32, NASA Grant NSG-2301, Mechanical Engineering, Virginia Polytechnic Institute and State University, Sept. 1980.

Pierce, F. J., J. D. Menna, and M. D. Harsh, "Preliminary Mean Flow and Reynolds Stress Measurements in a Pressure-Driven Three-Dimensional Turbulent Boundary Layer," Interim Rpt. #1, NASA Grant NSG-2301, Mechanical Engineering, Virginia Polytechnic Institute and State University, July 1981.

Pierce, F. J., M. D. Harsh, and J. D. Menna, "Interim Report on a Standard Test Case for a Pressure-Driven Three-Dimensional Turbulent Boundary Layer Including a Separated Flow Region," Interim Rpt. #2, NASA Grant NSG-2301, Mechanical Engineering, Virginia Polytechnic Institute and State University, January 1982.

Pierce, F. J., J. D. Menna, M. D. Harsh, and I. K. Tree, "Interim Report on a Complex Three-Dimensional Separated Turbulent Flow," Interim Rpt. #3, NASA Grant NSG-2301, Mechanical Engineering, Virginia Polytechnic Institute and State University, January 1983.

Pierce, F. J., and J. D. Menna, "A Three-Dimensional Turbulent Boundary Layer Upstream and Around a Junction Vortex Flow," VPI-E-84-83, Phase I NASA Final Report, June 1984.

Pierce, F. J., and M. D. Harsh, "An Experimental Investigation of a Turbulent Junction Vortex," VPI-E-85-4, Phase II NASA Final Report, February 1985.

The following is a list of publications in the open literature relating to the total project. It is noted that portions of the work cited below were supported initially by the NSF, and subsequently by the

Mechanical Engineering Department. The full list is presented for completeness.

Tennant, M. H., F. J. Pierce, and J. E. McAllister, "An Omnidirectional Wall Shear Meter," Journal of Fluids Engineering, Transactions of the ASME, Vol. 102, March 1980, pp. 251-258.

McAllister, J. E., F. J. Pierce, and M. H. Tennant, "Direct Force Wall Shear Measurements in a Pressure-Driven Three-Dimensional Turbulent Boundary Layer," Journal of Fluids Engineering, Transactions of the ASME, Vol. 104, June 1982, pp. 150-155.

McAllister, J. E., F. J. Pierce, and M. H. Tennant, "Preston Tube Calibrations and Direct Force Floating Element Measurements in a Two-Dimensional Turbulent Boundary Layer," Journal of Fluids Engineering, Transactions of the ASME, Vol. 104, June 1982, pp. 156-161.

Pierce, F. J., and J. E. McAllister, "Measurements in a Pressure-Driven and a Shear-Drive Three-Dimensional Turbulent Boundary Layer," in Three-Dimensional Turbulent Boundary Layers, IUTAM-Symposium Proceedings, Springer-Verlag, Berlin, 1982.

Pierce, F. J., J. E. McAllister, and M. H. Tennant, "Near-Wall Similarity in Three-Dimensional Turbulent Boundary Layers Part I: Model Review," in Three Dimensional Turbulent Shear Flows, ASME, New York, 1982.

Pierce, F. J., J. E. McAllister, and M. H. Tennant, "Near-Wall Similarity in Three-Dimensional Turbulent Boundary Layers Part II: Pressure-Driven Flow Results," in Three Dimensional Turbulent Shear Flows, ASME, New York, 1982.

Pierce, F. J., and J. E. McAllister, "Near-Wall Similarity in Three-Dimensional Turbulent Boundary Layers Part III: Shear-Driven Flow Results," in Three Dimensional Turbulent Shear Flows, ASME, New York, 1982.

Pierce, F. J., and M. D. Harsh, "Three-Dimensional Turbulent Boundary Layer Separation at the Junction of a Streamlined Cylinder with a Flat Plate," Proceedings of the Third International Symposium on Flow Visualization, Sept. 1983, pp. 59-63.

Pierce, F. J., J. E. McAllister, and M. H. Tennant, "A Review of Near-Wall Similarity Models in Three-Dimensional Turbulent Boundary Layers," Journal of Fluids Engineering, Transactions of the ASME, Vol. 105, Sept. 1983, pp. 251-256.

Pierce, F. J., J. E. McAllister, and M. H. Tennant, "Near-Wall Similarity in a Pressure-Driven Three-Dimensional Turbulent Boundary Layer," Journal of Fluids Engineering, Transactions of the ASME, Vol. 105, Sept. 1983, pp. 257-262.

Pierce, F. J., and J. E. McAllister, "Near-Wall Similarity in a Shear-Driven Three-Dimensional Turbulent Boundary Layer," Journal of Fluids Engineering, Transactions of the ASME, Vol. 105, Sept. 1983, pp. 263-269.